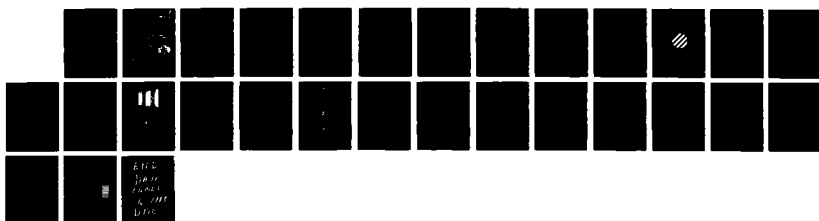AD-A192 051   AN INTERFEROMETRIC MEASUREMENT TECHNIQUE FOR RAILGUN   1/1
               STRUCTURES(U) ARMY BALLISTIC RESEARCH LAB ABERDEEN
               PROVING GROUND MD A ZIELINSKI ET AL. JAN 88
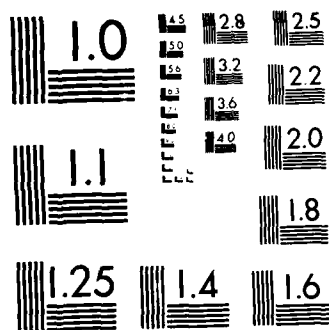
UNCLASSIFIED   BRL-MR-5646   F/G 19/6   NL

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

AD-A192 851

AD

MEMORANDUM REPORT BRL-MR-3646

AN INTERFEROMETRIC MEASUREMENT TECHNIQUE FOR RAILGUN STRUCTURES

ALEX ZIELINSKI
JEFFREY KEZERIAN
MAJ. JOSEPH BENO

JANUARY 1988

US ARMY BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

88 3 22 047

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION	1b. RESTRICTIVE MARKINGS
Unclassified	

2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT
N/A	
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
N/A	

4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
BRL-MR-3646	

6a. NAME OF PERFORMING ORGANIZATION	6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
US Army Ballistic Research Laboratory	SLCBR-TB	

6c. ADDRESS (City, State, and ZIP Code)	7b. ADDRESS (City, State, and ZIP Code)
Aberdeen Proving Ground, Maryland 21005-5066	

8a. NAME OF FUNDING / SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
US Army Ballistic Research Laboratory	SLCBR-D	

8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS			
Aberdeen Proving Ground, Maryland 21005-5066	PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
	62618A	AH80	00	

11. TITLE (Include Security Classification)

(U) An Interferometric Measurement Technique for Railgun Structures

12. PERSONAL AUTHOR(S)
Alexander Zielinski, Jeffrey Kezerian, and Maj. Joseph Beno

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
MR	FROM _____ TO _____		

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Interferometry Railgun
20	03	06	Bore expansion Magnetic Pressure
			Pulsed Power Electric Gun

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A technique to measure the expansion of a railgun under conditions of high magnetic stress has been developed. Bore deflections are detected by a Michelson interferometer arrangement during the application of a current pulse which produced repulsive forces similar to those in an actual projectile launch. This technique has been successfully used with two different barrel set-ups whose rails were electrically connected outside the bore at the muzzle. The method should prove valuable for testing a wide variety of electro-magnetic launcher structures owing to the small loading of the optics on the structure itself.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☒ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL
Alex Zielinski	301/278-5687	SLCBR-TB-EP

DD Form 1473, JUN 86   Previous editions are obsolete.   SECURITY CLASSIFICATION OF THIS PAGE

ACKNOWLEDGEMENT

Accession For	
NTIS GRA&I	X
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

DTIC
COPY
INSPECTED
1

TABLE OF CONTENTS

LIST OF FIGURES

I. INTRODUCTION

In a system designed to convert stored electrical energy to the energy of mechanical motion one is likely to produce large forces on the structure in addition to the desired forces. The problem of deflections of current carrying conductors and their effects on busbar supports has been studied in the power utility industry,[1] and more recently, in the development of electro-magnetic launchers.[2,3,4] The problem with busbars in the utility industry is aggravated by their having natural frequencies of a few hundred hertz so that mechanical resonance may be possible. During operation, electromagnetic launchers must cope with even higher transient currents than the utility industry must contend with under short circuit fault conditions. With the anti-cipated use of sequential pulsers (eg., Compulsators or other pulsed power supplies designed for high rate of fire) the EM gun community may also have to contend with resonance. In any of these cases, the failure of support structures resulting from transient magnetic forces can lead to degraded performance or catastrophic failure. A study of the structural behavior of a mechanical system can assist in preventing failure and optimizing the design for a given performance. In developing railguns as efficient, long life devices, an understanding of material deformation under pulse loading is necessary. The bore's dimensional integrity is important for both the armature and the projectile as they travel the length of the rail pair. Deformations may affect not only in bore conditions such as friction, balloting, and launch attitude, but also armature function; the fit of the armature to the bore is critical since the armature must complete the rail to rail circuit by maintaining two high current, sliding, electrical contacts.

The railgun type of electromagnetic launcher has been widely studied. The essential features of the railgun are shown in Fig. 1. In the simplest form of the device, current is applied to a normally stationary, parallel pair of conducting rails. A conductor, either solid or gaseous, free to slide between the rail pair, completes the circuit and also carries the same current. The moving conducting element is called the armature. The interaction between the current and its magnetic field produces a force tending to expand the current carrying loop; this leads, of course, to acceleration of the armature. Unfortunately, the same interaction which produces projectile acceleration also produces a transient, bore-distorting, replusive force between the rails.

Interferometry is a technique which can be used to measure change in displacement of an object. Figure 2 is a schematic of a simple laser interfero-meter which shows the process of splitting a beam of coherent, monochromatic light into two beams. Beam A-D, the reference beam, never changes in length; beam A-B-C, the object beam, is reflected by the objects that will be moving. Both beams are reflected back on themselves and recombine at the splitter. This phase difference with different path lengths produces either constructive or destructive interference of the beams. As the path length of the object beam changes the alternatively constructive and destructive interference produces a sequence of light and dark fringes. Since the fringes result from phase difference in light of known wavelength a relationship between the number of fringes and movement of the object may be determined. In dynamic tests, an oscilloscope records the time-varying output of a simple photodetector which senses the varying light intensity as fringes are produced. From this record the actual change in rail separation versus time may be determined.
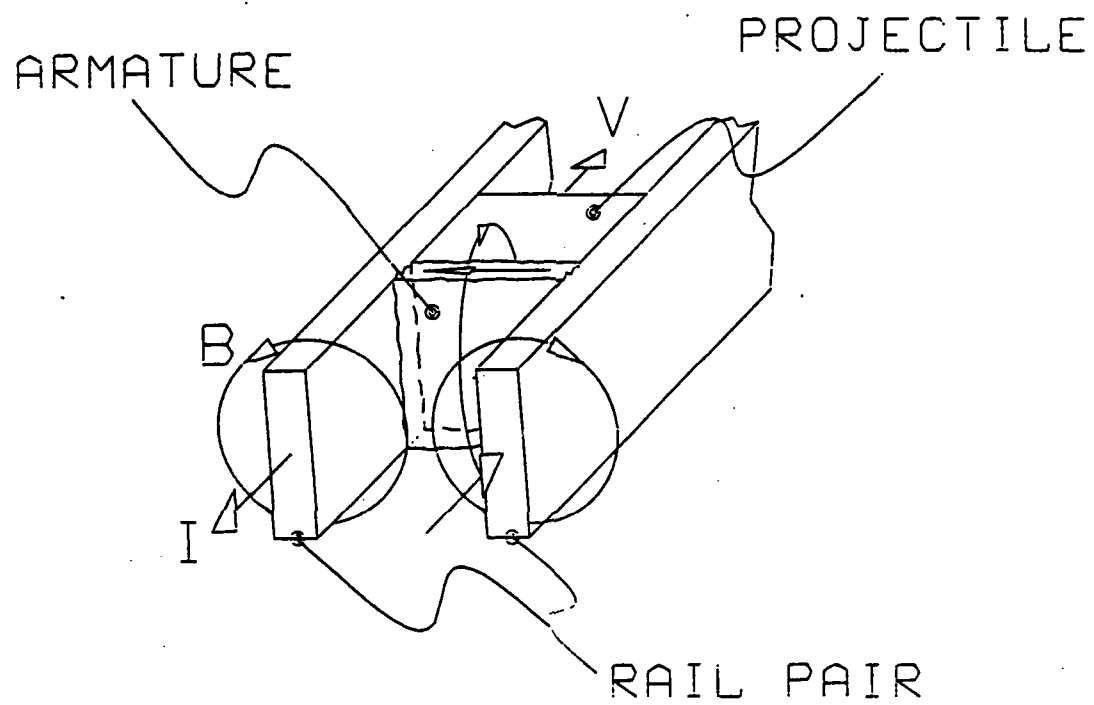
1

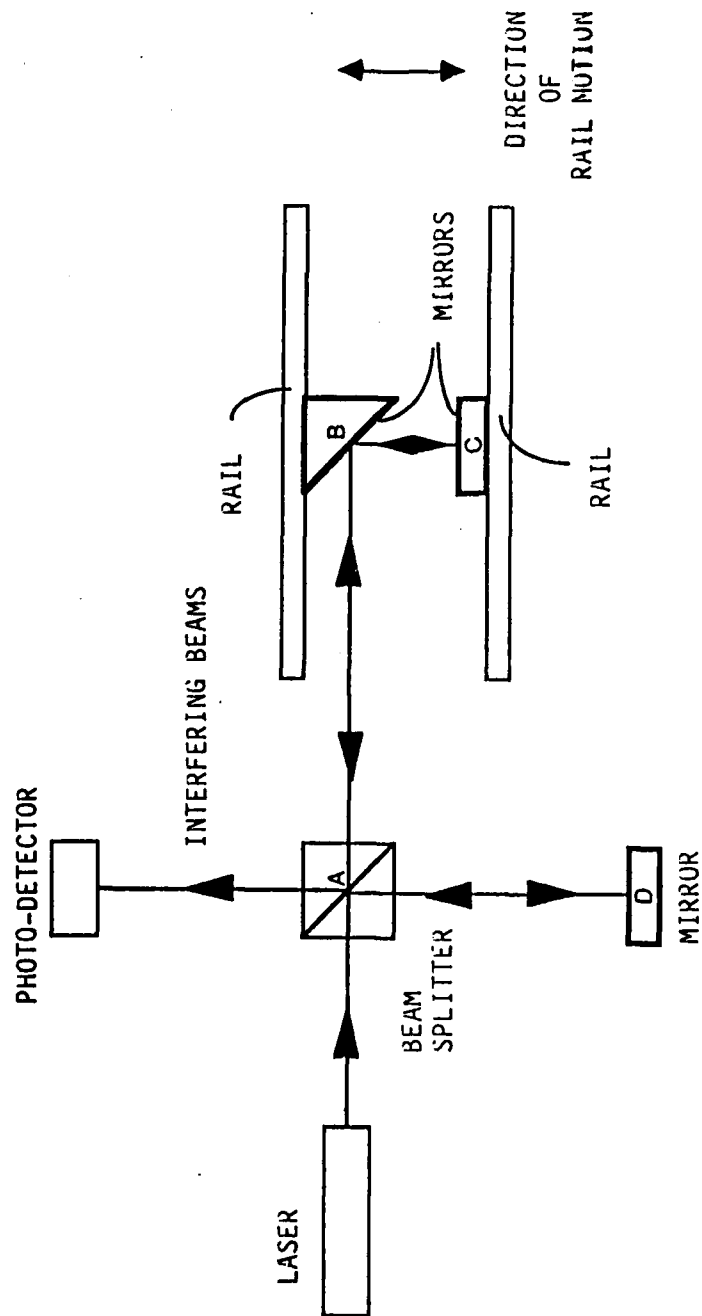Figure 1. Essential Features of an Electromagnetic Railgun.

Figure 2. Interferometric Arrangement for Measurement of Rail Displacement.

3

In the work reported here, two sets of experiments were performed. The first consisted of a pair of rudimentary conducting fixed parallel aluminum beams, pulsed with currents less than 5,000 amperes, and the second was a short electromagnetic railgun barrel section designed for a peak pressure of 1.0 GPa (145 ksi) and pulsed with currents greater than 100,000 amperes.

II. INTERFEREROMETER ARRANGEMENT

The interferometric components and their arrangement employed in both the table top experiments (aluminum beams) and the short barrel experiments are shown in Fig. 2. The laser light is divided by the beam splitter into reference and object paths. The path A-B-C-B-A changes length as the rails separate, the path A-D-A remains fixed. As mirrors B and C move apart, the interference pattern shifts at the detector. A path length change in A-B-C-B-A of one wavelength moves the fringe pattern by a given distance across the detector. An interference pattern of light and dark fringes is created similar to that shown in Fig. 3.

To determine how many fringes pass in front of the detector for a given change in rail pair separation let us assume that each mirror moves a distance of $\delta/2$, refer to Fig. 4. The original optical path is A-B1-C1-B1-A and the displaced path is A-B2-C2-B2-A. It can be seen that the total displaced path A-B2-C2-B2-A is longer than the original path A-B1-C1-B1-A by an amount equal to 2 δ. The number of fringes passing the detector is 2 δ/λ, where λ is the laser wavelength. Therefore the number of voltage waveform cycles per unit time on the oscilloscope is proportional to the rail pair separation change per unit time and is given by:

$$\delta(t) = N(t) * \lambda/2$$

where $N(t)$ is the number of detected peaks occurring in unit time.

III. EXPERIMENT: MECHANICAL AND ELECTRICAL

The table top experimental set-up and circuit used to provide power are shown schematically in Fig. 5. The aluminum rails are 2.286 mm (0.09 inch) thick, 146 mm (5.75 inches) long and 38.1 mm (1.5 inches) high with a nominal rail-to-rail separation distance of 25.4 mm (1 inch). Only the breech and muzzle ends of the rails are anchored to fiberglass/epoxy laminate (G-11) supports. At the breech a 5/8-inch bolt into a copper block is used to connect the current leads (12 gage wire) to the rails. Since no projectiles were used, the rails were shorted at the muzzle using two 3/8-inch steel bolts. The mirror, C, is mounted to one rail with double sided tape while the other mirror, B, is held at a 45 degree angle by a plexiglass mount attached to the other rail in the same manner. Both mirrors were located at the axial and transverse center of the rails.

The pulsing circuit for the table top experiment was designed to provide a current rise time of 120 microseconds which was expected for the short barrel experiments. The required total inductance for the table top pulser
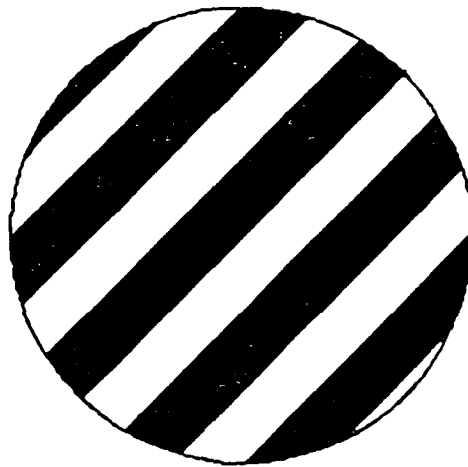
4

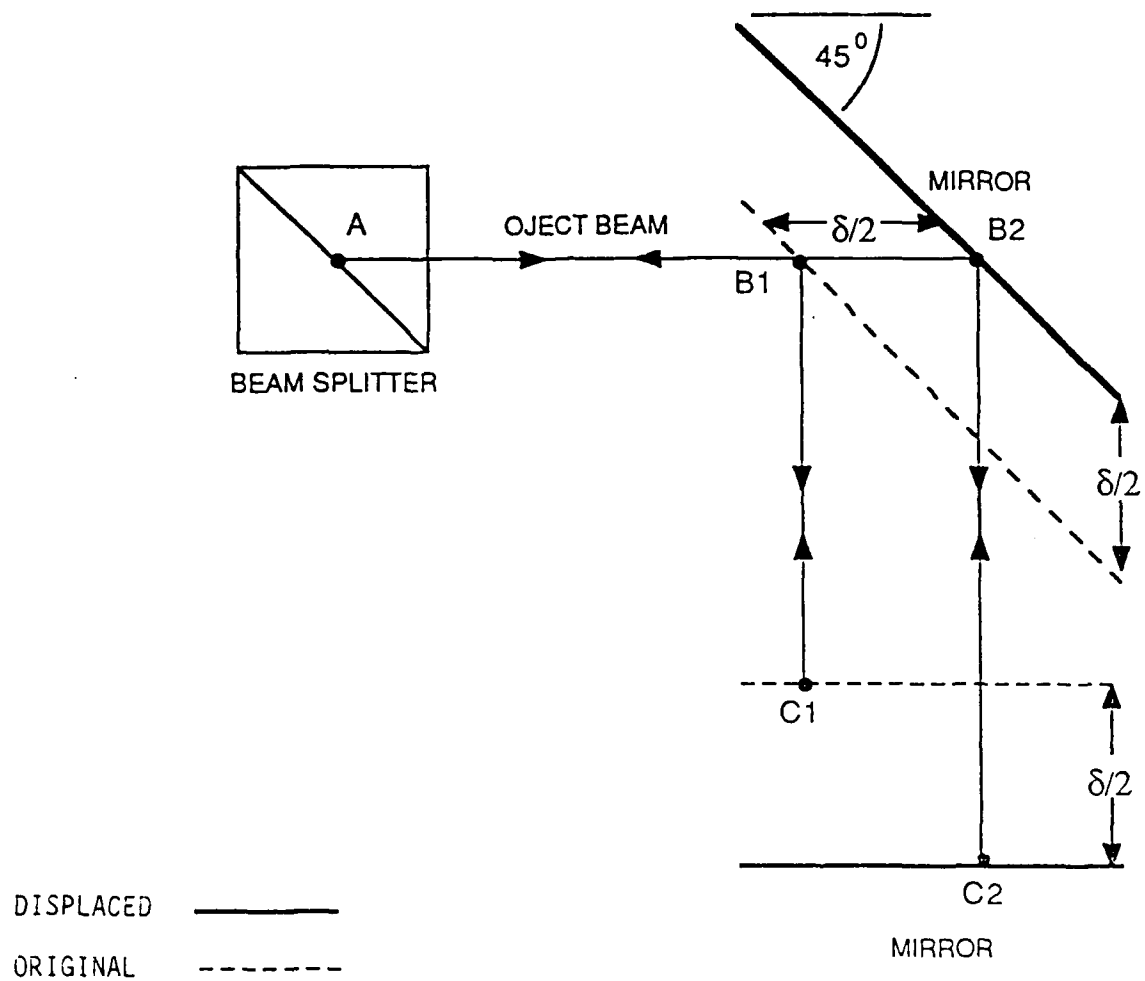Figure 3.   Illustration of an Interference Fringe Pattern.

5

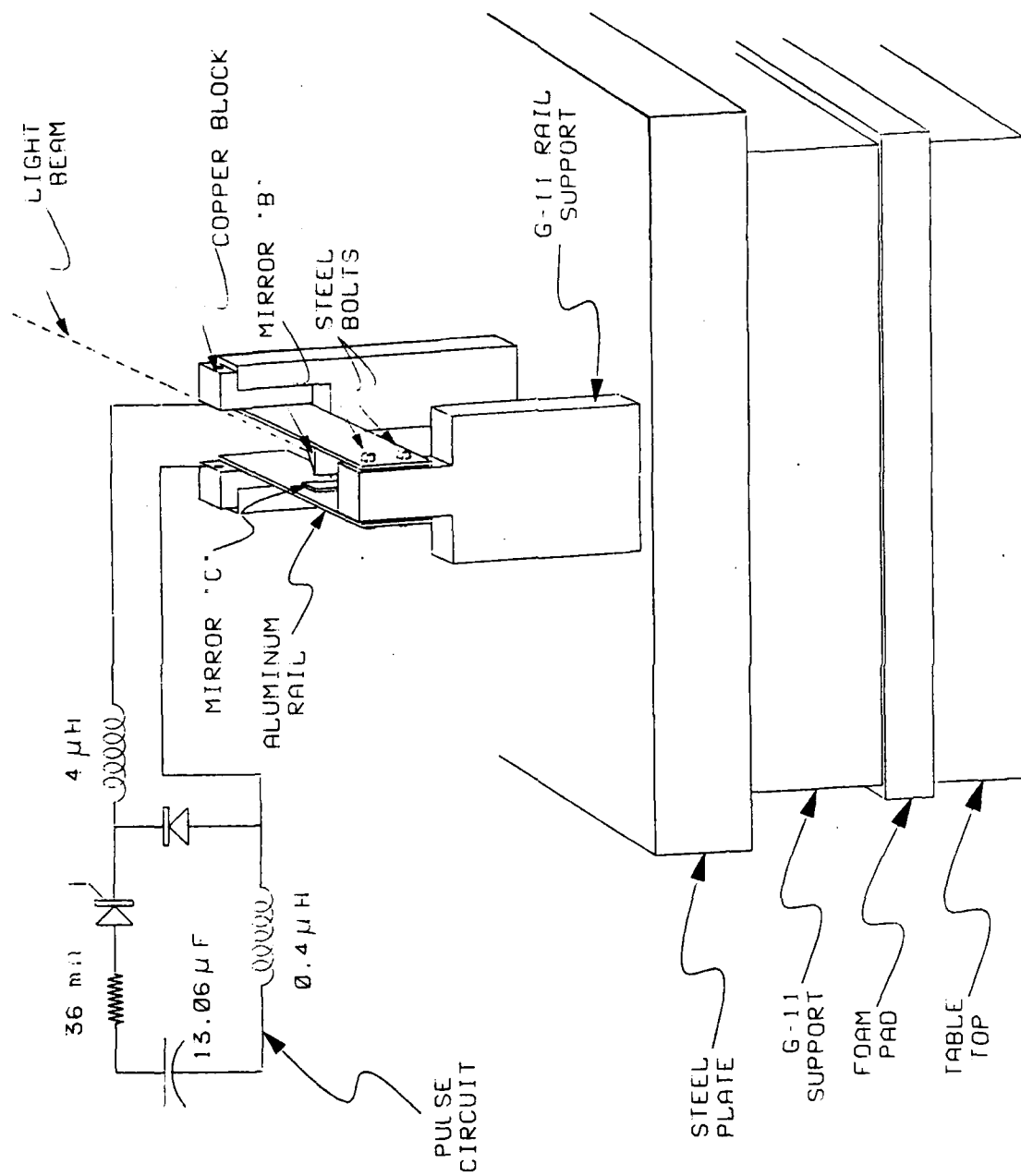Figure 4. Detailed Geometric Diagram for the Object Beam Path Length.

Figure 5. Component Placement and Equivalent Circuit Schematic for the Table Top Experiment.

was calculated to be:

$$L_{tot} \approx 4 * t_{pk}^2 / \pi^2 * Cap$$

where tpk is the time for current to reach peak and Cap is the pulser capacitance. This yields an inductance of 4.4 microhenries. Most of this inductance (4.0 microhenries) has to be provided by an inductor in the form of a single layer solenoid. Using 12 gage wire and a 4-inch diameter form, the required number of turns to obtain an inductance of 4 microhenries is found from:[5]

$$N = [L * (9a + 10b)]^{1/2}/a$$

where, L is the inductance in microhenries, a is the mean radius of the solenoid and b is the length of the solenoid in inches. The calculated maximum obtainable bank current (resistance included) with the bank fully charged is 4973 amperes. This translates to an applied load per unit rail length of 153 N/m (0.88 lb/in) to the rail surface. For this static beam analysis predicts a maximum bore deflection of 24 micrometers (0.94 mils) at maximum charge.

A Rogowski coil was used to measure the circuit di/dt. The coil has an output conversion factor of 15.9 amps/volt-microsecond. The optical fringe detector consisted of a RCA hybrid silicon photodiode with integral preamplifier module. The output of the circuit was fed into a capacitive AC coupler with a 50-ohm terminator. The data was collected using a Nicolet 2090 oscilloscope.

For the short barrel experiments a different power source was used and is described elsewhere.[6,7] Also, the mirrors were mounted in the bore and attached to the rails with epoxy. The interferometer was set up much the same way as for the table top experiment. The available current for these tests was greater than 100,000 amperes. Since the system energy was larger than in the table top experiments much more rigid optical supports were needed to control vibrations.

IV. OPTICAL AND MECHANICAL CONSIDERATIONS

The optical equipment was set up with several considerations in mind. First, the optical path differences must be within the coherence length of the laser. Since this length was unknown, any problem was circumvented by making the path lengths nearly equal.

A second consideration was the system's sensitivity. Because the interferometer will measure displacements smaller than an optical wavelength, extremely small vibrations result in fringes passing the detector. To avoid these small vibrations the apparatus was assembled on a massive board isolated by mounts of low stiffness. Thus, only low amplitude, low frequency vibrations were transferred to the equipment. The movement of the rails during a

current pulse produced temporal changes in the interference pattern which are significantly higher in frequency than those produced by external vibrations within the test area.

To avoid unwanted interference patterns that occur when the beam is reflected back on itself at the unsilvered interfaces of the beam splitter, the splitter was tilted slightly requiring mirror "D" to be moved for compensation. Now the two paths A-D and A-B in Fig. 2 become non-perpendicular and secondary interference patterns do not appear where the detector is located. Secondary reflections at the flat mirrors were eliminated by the use of front-surface silvered mirrors.

In the short barrel, high current experiments the two rail mirrors were unintentionally misaligned slightly and this resulted in the incoming beam, A-B being off axis with the return beam, B-A. This was compensated by adjustment of the trajectory of the incoming beam. Also, the reference beam optics were mounted on a 1 inch thick, G-11 platform bolted to the muzzle end of the barrel. A fiber optic cable transmitted the interference pattern to the detector a few meters away.

The above considerations were generally easy to compensate for and did not significantly hinder the experiment once the initial set-up was refined.

V. RESULTS

In the table top experiment the capacitor bank current was limited to less than 5000 amperes. There was no containment structure to keep the aluminum rail pair from deflecting. In this configuration it was found that measurable deflections occurred even with low currents. The short barrel section structure was designed for a peak pressure of 1.0 GPa (145 ksi) and therefore currents greater than 100,000 amperes were needed to produce detectable bore deflections.

Five tests were performed on the table top experiment at different bank energies. For each energy similar waveforms were observed. A typical detector waveform output recorded on a Nicolet 2090 oscilloscope is shown in Fig. 6a. The expansion of this waveform for the first 800 microseconds is shown in Fig. 6b. In the first 800 microseconds 43 fringes moved across the detector. The velocity of the rails is directly related to the instantaneous frequency of the output signal. Maximum velocity was reached near 300 microseconds. The aluminum rails used in the table top experiment exhibited a slightly damped oscillatory motion from a single current pulse. One complete cycle of mechanical oscillation was observed to have a frequency of 280 hertz. The current and deflection curves versus time for one test are plotted in Fig. 7. Figure 8 is a summary plot of peak current (at 115 microseconds) versus peak bore deflection (at 728 microseconds) for the five small scale tests. The bore deflections scale as the square of the current.

Two tests were performed on the short barrel section· one where 110,000 amperes was delivered to the barrel section (capacitor voltage = 1000 volts), and one where 314,000 amperes was produced (capacitor voltage = 2500 volts). Shown in Fig. 9 is the optical fringe detector output for the higher current test. This total trace is comprised of five separate waveforms, each recorded

9
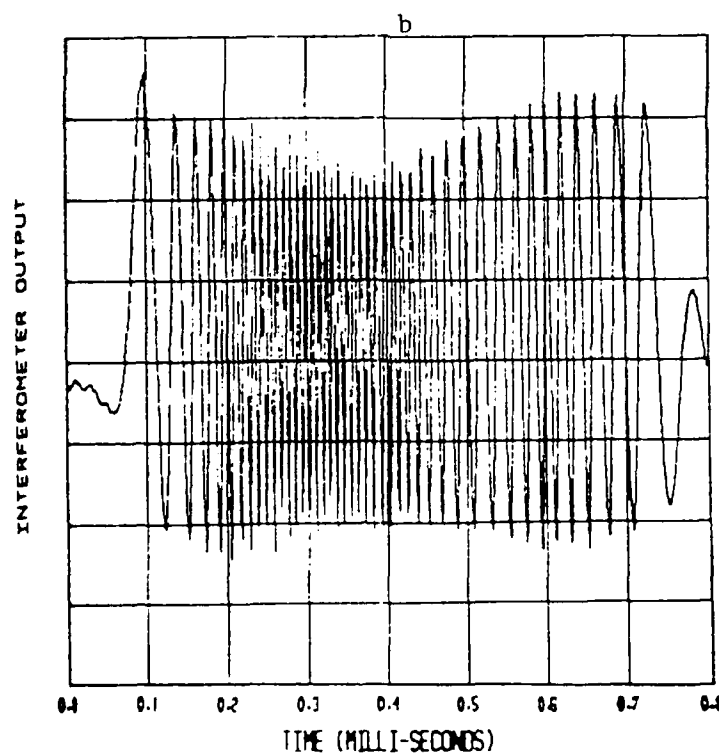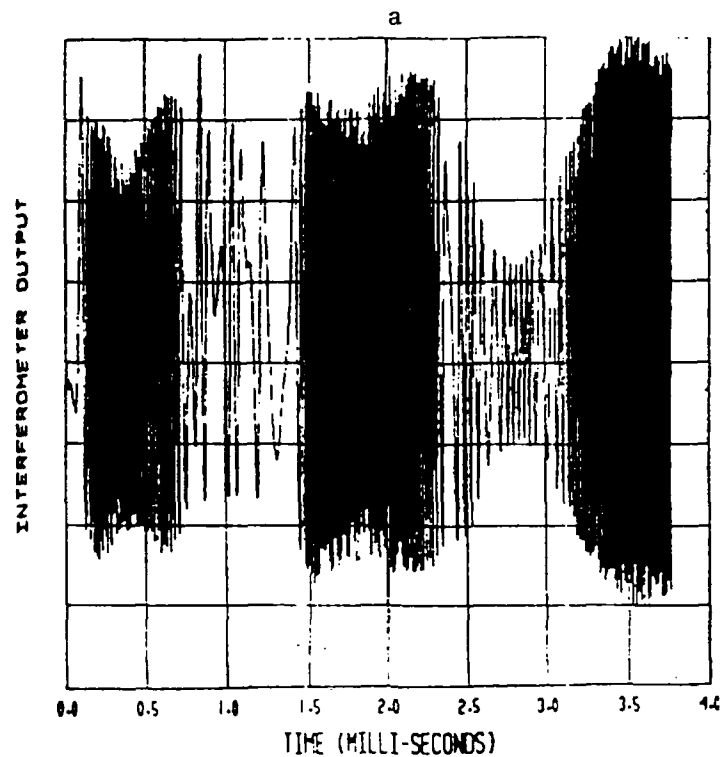
Figure 6. Fringe Detector Output (upper plot) and Waveform Expansion for the First 800 Microseconds (lower plot) for the Table Top Experiment.

10
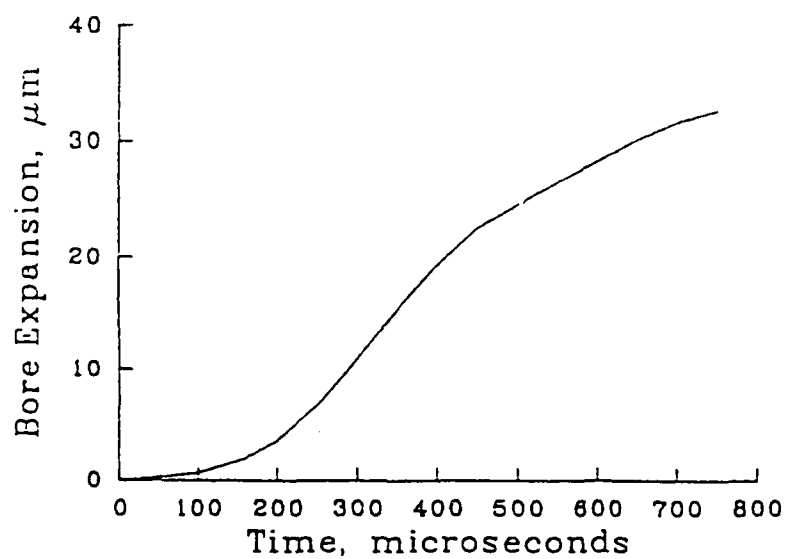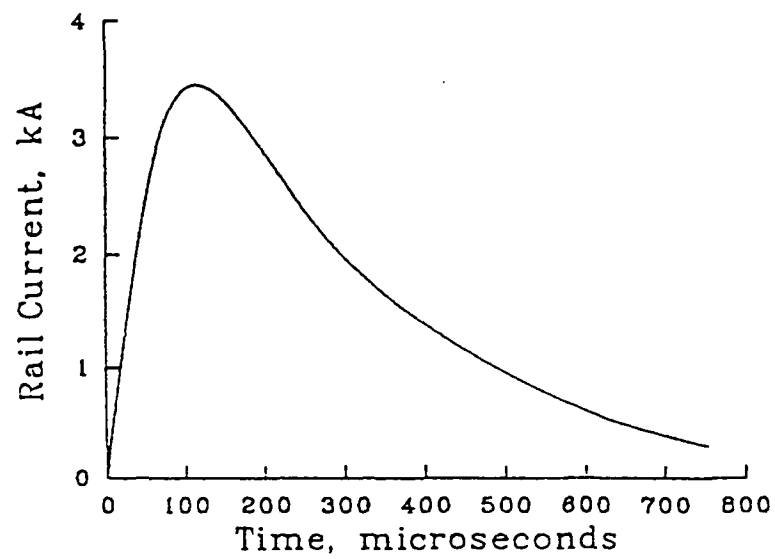
Figure 7. Typical Curent Trace (upper curve) and Bore Expansion (lower curve) for the Table Top Experiment.
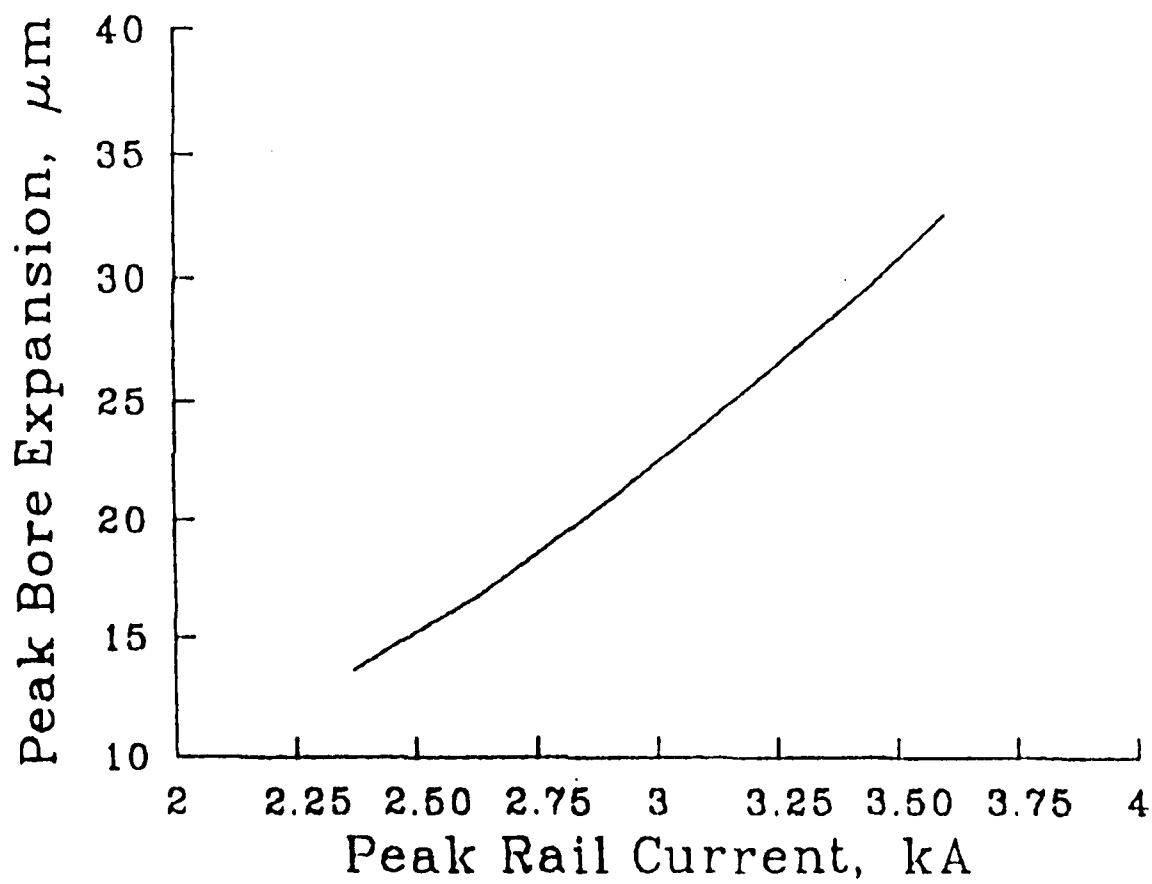
Figure 8.   Peak Bore Expansion versus Peak Current for the Table Top
Experiments.
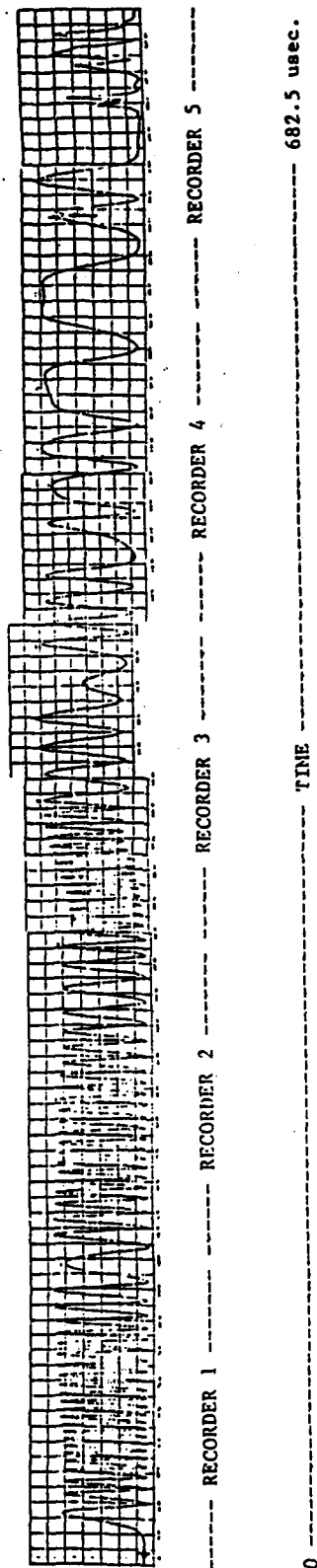
Figure 9. Fringe Detector output versus Time for the Short Barrel Section. Initial Capacitor Voltage = 2500 volts, and Peak Barrel Current = 314,000 amperes.

13

on a Tektronix 390 AD transient digitizer operated in the serial mode. The reduced fringe detector signal amplitude concurrent with the lower signal frequency is representative of peak deflection and approximately zero rail velocity. This condition occurred twice; on the 24th fringe (131.5 microseconds) and on the 65th fringe (380.5 microseconds). After the 74th fringe (604 microseconds) rail movement has stopped and only background vibrations are sensed by the detector. A plot of the bore expansion versus time for both the low and high current tests, are shown in the bottom portion of Fig. 10. The peak current (upper portion of Fig. 10) occurred at 112 microseconds while the maximum bore deflection occurred between 117 and 143 microseconds.

In the table top experiment the aluminum rails have moved less than 10% of their peak deflection at peak current where as the short barrel-section rails have moved 95% of their final deflection at peak current. Maximum current in the table top experiment was 3600 amperes, and was 314,000 amperes in the short barrel tests. The corresponding bore expansions obtained were 32.5 micrometers (1.28E-3 inches) and 7.6 micrometers (0.298E-3 inches), respectively.

VI. CONCLUSION

The laser interferometric technique has proven useful in making small, dynamic deflection measurements in systems under large electrical and mechanical stress. The interference signal pattern was easily transmitted to the detector a few meters away via a fiber optic cable. Two drawbacks to this technique become evident when recording and analyzing the data. First, for large deflections a trade-off has to be made between the sampling rate and the window width of the oscilloscope. Second, with this technique the interferometer measures separation change without indicating whether the rails have, expanded, contracted, or translated together. This can produce some ambiguity in the data reduction if the initial direction of rail motion is not known. The maximum separation occurs when the waveform becomes reduced in both frequency and amplitude. When no rail motion is occurring only system vibrations are observed by the detector and these appear as slight noise in the signal. The needed accuracy in these experiments does not require the use of expensive optical components although access to the proper equipment greatly facilitated the set-up and alignment of the interferometer. The technique allows immediate return of the data and excellent measurement accuracy.

With electromagnetic gun developers requiring much stiffer railgun barrels this technique should provide a valuable tool for structural diagnostics and verification of finite element analysis.

14
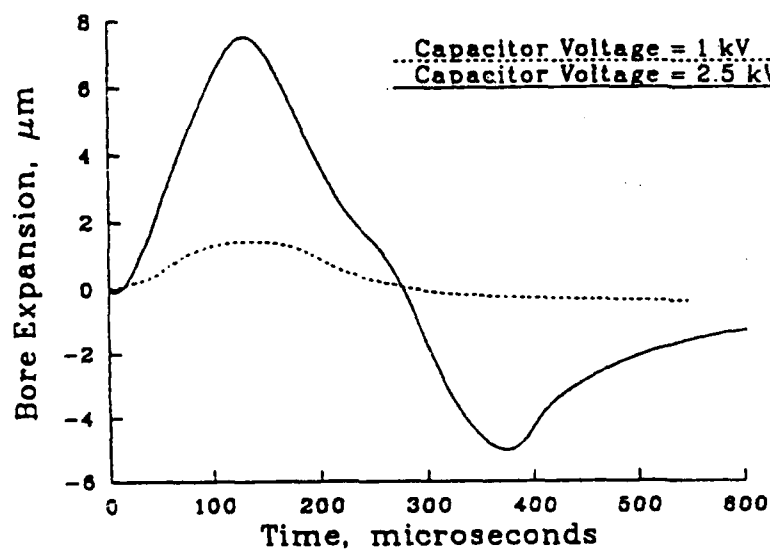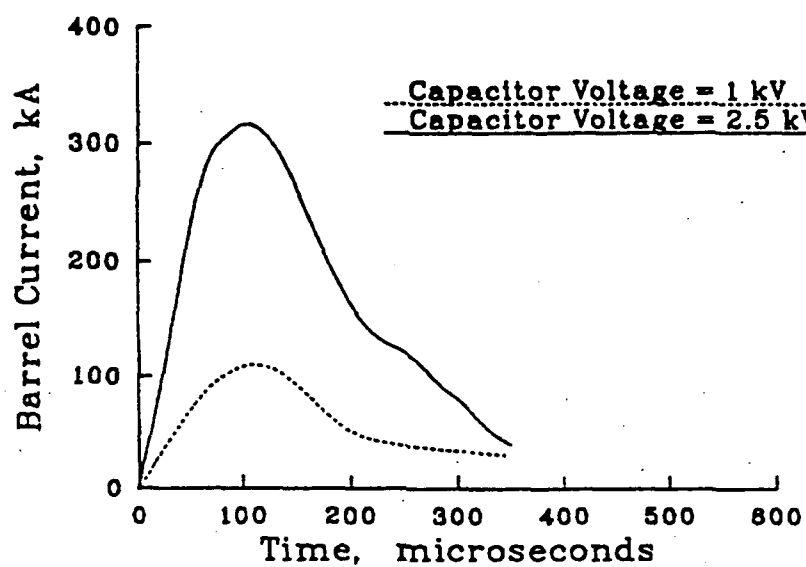
Figure 10. Barrel Currents (upper plot) and Bore Expansions (lower plot) versus Time for Two Pulse Tests.

15

REFERENCES

1. Schuring, O. R., and Sayre, M. F., "Mechanical Stresses in Busbar Supports During Short Circuits", Journal of Amererican Institute of Electrical Engineers, pp. 44, 1925

2. Zimmerman, E. L., Fowler, C. M., Foley, E., and Parker, J. V., "HIMASS Electromagnetic Launcher at Los Alamos," IEEE Transactions on Magnetics, Vol. Mag-22, pp. 1823-1825, Nov 1986.

3. Davidson, R. F., Cook, W. A., Rabern, D. A., and Schnurr, N. M., "Predicting Bore Deformations and Launcher Stresss in Railguns," IEEE Transactions on Magnetics, Vol. Mag-22, pp. 1435-1440, Nov 1986.

4. Wang, S. Y., "Structural Response of a Rail Accelerator," IEEE Transactions on Magnetics, Vol. Mag-22, pp. 356-359, March 1984.

5. Terman, F., Radio Engineers' Handbook, McGraw-Hill Book Company, Inc., New York, NY, 1943.

6. Zielinski, A., Jamison, K., and Bennett, J., Pulse Current Transformer for Low Inductive Loads, BRL-MR-3626, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, Oct, 1987.

7. Pappas, J., Driga, M. D., and Weldon, W., High Current Coaxial Pulse Transformer for Railgun Applications, Paper presented at the 5th IEEE Pulsed Power Conference, Arlington, VA, June, 1985.

DISTRIBUTION LIST

No. of Copies	Organization	No. Of Copies	Organizations
2	Administrator Defense Technical Info Center ATTN: DTIC-FDAC Cameron Station Alexandria, VA 22304-6145	3	Commander U. S. AMCCOM ARDEC CCAC Benet Weapons Laboratory ATTN: SMCAR-CCB-TL SMCAR-LCB-DS Dr. C. A. Andrade Dr. Patrick Vottis Watervliet, NY 12189-4050
10	C. I. A. OIR/DB/Standard GE47 HQ Washington, DC 20505	1	Commander US Army Armament, Munitions and Chemical Command ATTN: AMSMC-IMP-L Rock Island, IL 61299-7300
1	HQDA ATTN: DAMA-ART-M Washington, DC 20310	1	Commander US Army Aviation System Command ATTN: AMSAV-ES 4300 Goodfellow Blvd. St. Louis, MO 63120-1798
1	Commander US Army Materiel Command ATTN: AMCDRA-ST 5001 Eisenhower Avenue Alexandria, VA 22333-0001	1	Director US Army Air Aviation Research and Technology Activity Ames Research Center Moffett Field, CA 94035-1099
1	Commander U.S. Army Armament Research Development & Engr Center ATTN: SMCAR-MSI Picatinny Arsenal, NJ 07801-5001	1	Commander US Army Communications - Electronics Command ATTN: AMSEL-ED Fort Monmouth, NJ 07703-5000
1	Commander US Army ARDEC ATTN: SMCAR-TDC Picatinny Arsenal, NJ 07801-5001		
1	Commander ARDEC,CCAC ATTN: SMCAR-SCA-E Mr. H. Kahn Picatinny Arsenal, NJ 07801-5001	1	Commander CECOM R&D Technical Library ATTN: AMSEL-IM-L (Report Section) B.2700 Fort Monmouth, NJ 07703-5000
3	Commander ARDEC, FSAC ATTN: SMCAR-FSA-E Dr. Thaddeus Gora Mr. Harry Moore Mr. John Bennett Picatinny Arsenal, NJ 07801-5001	1	Commander US Army Missile Command Research, Development, and Engineering Center ATTN: AMSMI-RD Redstone Arsenal, AL 35898

No. Of Copies	Organization	No. Of Copies	Organization
1	Commander US Army Tank Automotive Command ATTN: AMSTA-TSL Warren, MI 48090	2	Director Defense Advanced Research Projects Agency ATTN: Dr. Harry Fair Dr. Peter Kemmey 1400 Wilson Blvd. Arlington, VA 22209
1	Commander US Army Development and Employment Agency ATTN: MODE-ORO Fort Lewis, WA 98433-5000	1	Director US Army TRADOC Analysis Center ATTN: ATOR-TSL White Sands Missile Range, NM 88002-5502
1	Commander US Army Research Office ATTN: Dr. Mikael Ciftan Research Triangle Park, NC 27709-2211	1	Commander Naval Surface Weapons Center ATTN: Mr. P. T. Adams, Code G-35 Dahlgren, VA 22448
5	Commander Strategic Defense Initiative Organization ATTN: SDIO/KEW BG M. O'Neil Maj. R. Lennard SDIO/IST Dr. J. Ionson Dr. L. Caveny Washington, DC 20301-7100	2	Commander Naval Research Laboratory ATTN: Mr. Ihor M. Vitkovitsky Code 4701 Mr. Richard Ford, Code 4774 Washington, DC 20375
1	Commandant US Army Infantry School ATTN: ATSH-CD-CS-OR Fort Benning, GA 31905-5400	1	AFAPL/POCS-2 ATTN: Dr. Charles E. Oberly Wright Patterson AFB Dayton, OH 45433
		1	AFATL/DOIL (Tech Info Center) Eglin AFB, FL 32542-5438
1	Director US Army Missile Space Intelligence Center ATTN: AMSMI-YDL Redstone Arsenal, AL 35898-5500	1	AFWL/SUL Kirtland AFB, NM 87117
1	Director Ballistic Missile Defense Advanced Technology Center ATTN: BMDATC-M Dr. Darrell B. Harmon P. O. Box 1500 Hunstville, AL 35807	6	Air Force Armament Laboratory ATTN: AFATL/DLODL ATTN: AFATL/DLYS, Cpt. Jere Brown Lt. J. Martin Mr. Kenneth Cobb Lt D. Jensen Dr. Timothy Aden Eglin AFB, FL 32542-5000

No. Of Copies	Organization	No. Of Copies	Organization
1	Director Brookhaven National Laboratory ATTN: Dr. J. R. Powell, Bldg 129 Upton, NY 11973	3	Electromagnetic Research Inc. ATTN: Dr. Henry Kalm Dr. Peter Mongeau Dr. William Snow 625 Putnam Avenue Cambridge, MA 62139
3	Director Los Alamos National Laboratory ATTN: MSG 787, Mr. Max Fowler Dr. Gerry V. Parker Dr. M. Parsons, MS 1220 Los Alamos, NM 87545	2	GA Technologies, Inc. ATTN: Dr. Robert Bourque Dr. L. Holland P. O. Box 85608 San Diego, CA 92138
1	Director Lawrence Livermore National Lab ATTN: Dr. R. S. Hawke, L-156 P. O. Box 808 Livermore, CA 94550	1	General Dynamics ATTN: Dr. Jamie Cuadros P. O. Box 2507 Pomona, CA 91766
1	Director Sandia National Laboratory ATTN: Dr. Maynard Cowan, Dept 1220 P. O. Box 5800 Albuquerque, NM 87185	1	General Electric Company ATTN: Dr. J. Hickey Bldg 37, Rm 380 1 River Rd Schnectady, NY 12345
1	Astron Research & Engineering ATTN: Mr. Charles Powars 2028 Old Middlefield Way Mountain View, CA 94043	1	General Research Corporation ATTN: Dr. William Isbell 5383 Hallister Avenue Santa Barbara, CA 93111
2	Austin Research Associates ATTN: Dr. Millard L. Sloan Dr. William E. Drummond 1091 Rutland Drive Austin, TX 87858	1	Gould Defense Systems, Inc. Ocean Systems Division ATTN: Dr. Donald M. McEligot One Corporate Park Newport Corporate Park Middletown, NY 02840
1	BMD Corporation ATTN: Dr. David Elkin 10260 Old Columbia Rd. Columbia, MD 21046	1	GT Devices ATTN: Dr. Derek Tidman 5705-A General Washington Drive Alexandria, VA 22312
1	Boeing Aerospace Company ATTN: Dr. J. E. Shrader P. O. Box 3999 Seattle, WA 98134	2	IAP Research, Inc. ATTN: Dr. John P. Barber Dr. David P. Bauer 2763 Culver Ave Dayton, OH 45429-3723

No. Of Copies	Organization	No. Of Copies	Organization
2	LTV Aerospace & Defense Company ATTN: Dr. Michael M. Tower Dr. C. H. Height M/S TH-38 P. O. Box 650003 Dallas, TX 75265-0003	1	Science Applications, Inc. Plasma Physics Division ATTN: Dr. Edward L. Kane John Connolly 1710 Goodrich Drive, T4 McLean, VA 22102
3	Maxwell Laboratories ATTN: Dr. Rolf Dethlefson Dr. Michael M. Holland Dr. Mark Wilkinson 8888 Balboa Avenue San Diego, CA 92123	2	Science Applications, Inc. ATTN: Dr. Ed O'Donnell Dr. Miles Palmer 2 Clifford Drive Shalimar, FL 32579
1	NASA Lewis Research Center ATTN: Lynette Zana, MS 501-7 2100 Brook Park Rd Cleveland, OH 44135	1	Science Applications, Inc. ATTN: Dr. Dan Barnes 206 Wild Basin Rd, Suite 103 Austin, TX 78746
1	Pacific-Sierra Research Corp. ATTN: Dr. Gene E. McClellan 1401 Wilson Blvd Arlington, VA 22209	3	Sparta, Inc. ATTN: Mr. Stuart Rosenwasser Mr. Dan Stevenson Mr. Dan Vrable 1104 B Camino Del Mar Del Mar, CA 92014
3	Physics International Company ATTN: Dr. A. L. Brooks Dr. Edward B. Goldman Dr. Frank Davies 2700 Merced Street San Leandro, CA 945577	1	System Planning Corporation ATTN: Donald E. Shaw 1500 Wilson Blvd Arlington, VA 22209
1	R&D Associates ATTN: Dr. Peter Turchi P. O. Box 9695 Marina del Rey, CA 90291	2	Westinghouse Electric Corp. Marine Division ATTN: Dr. Dan Omry Dr. Ian R. McNab 401 E. Hendy Avenue Sunnyvale, CA 94088-3499
1	Rockwell International Rocketdyne Division ATTN: Dr. Earl Deder, MS HB14 6633 Canoga Avenue Canoga Park, CA 91304	1	Westinghouse R&D Laboratory ATTN: Dr. Bruce Swanson 1310 Beulah Rd Pittsburgh, PA 15233
1	Science Applications, Inc. ATTN: Mr. Robert Acebal 1503 Johnson Ferry Road Suite 100 Marietta, GA 30062	2	Auburn University ATTN: Dr. R. F. Askew, Dir Leach Nuclear Science Center ATTN: Dr. E. J. Clothiaux Department of Phyics Auburn, AL 36849-3501

No of
Copies   Organization

1   Texas Tech University
Department of Electrical
  Engineering/Computer Science
ATTN: Dr. M. Kristiansen
Lubbock, TX 79409-4439

1   Tuskegee Institute
Dept. of Mechanical Engineering
ATTN: Pradosh Ray
Tuskegee, AL 36088

1   University of Alabama in
Huntsville
School of Science & Engr
ATTN: Dr. C. H. Chen
Huntsville, AL 35899

1   University of Miami
ATTN: Dr. M. A. Huerta
Physics Dept
P. O. Box 248046
Coral Gables, FL 33124

1   University of Tennessee
 Space Institute
ATTN: Dr. Dennis Keefer
Tullahoma, TN 37388-8897

3   University of Texas
Center for Electromechanics
Balcones Research Center
ATTN: Mr. William Weldon
       Mr. Raymond Zaworka
       Dr. Dennis Peterson
       Mr. John Gully
10100 Burnet Rd, Bldg 133
Austin, TX 78758

Aberdeen Proving Ground
     Dir, USAMSAA
      ATTN: AMXSY-D
            AMXSY-MP, H. Cohen
     Cdr, USATECOM
      ATTN: AMSTE-TO-F
     Cdr, CRDC, AMCCOM
      ATTN: SMCCR-RSP-A

23

USER EVALUATION SHEET/CHANGE OF ADDRESS

This Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers to the items/questions below will aid us in our efforts.

1. BRL Report Number_____Date of Report_____

2. Date Report Received_____

3. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.)_____

_____

_____

4. How specifically, is the report being used? (Information source, design data, procedure, source of ideas, etc.)_____

_____

_____

5. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided or efficiencies achieved, etc? If so, please elaborate._____

_____

_____

6. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.)

_____

_____

_____

CURRENT
ADDRESS

Name_____

Organization_____

Address_____

City, State, Zip

7. If indicating a Change of Address or Address Correction, please provide the New or Correct Address in Block 6 above and the Old or Incorrect address below.

OLD
ADDRESS

Name_____

Organization_____

Address_____

City, State, Zip

(Remove this sheet, fold as indicated, staple or tape closed, and mail.)

- - - - - - - - - - FOLD HERE - - - - - - - - - -

Director
US Army Ballistic Research Laboratory
ATTN: DRXBR-OD-ST
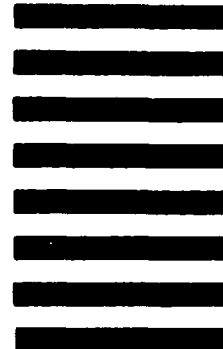Aberdeen Proving Ground, MD 21005-5066

||||||

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE. $300

BUSINESS REPLY MAIL
FIRST CLASS   PERMIT NO 12062   WASHINGTON, DC

POSTAGE WILL BE PAID BY DEPARTMENT OF THE ARMY

Director
US Army Ballistic Research Laboratory
ATTN: DRXBR-OD-ST
Aberdeen Proving Ground, MD 21005-9989

- - - - - - - - - - FOLD HERE - - - - - - - - - -

END

DATE

FILMED

6-1988

DTIC